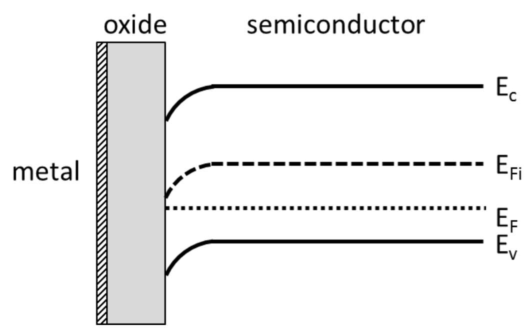
David Kirby

ECE 371
Materials and Devices
HW #8
Due: Thursday 12/05/19 at the beginning of class

*Textbook problems from Neamen 4th Edition Ch. 10. Assume the semiconductor is silicon and the oxide is silicon dioxide in these problems. You can use Fig. 10.16 to find the metal-semiconductor work function difference.

1) Consider a non-ideal MOS structure with the following band diagram at zero gate bias (V_G = 0).



a) Is this nMOS or pMOS technology?
b) What is the polarity (+ or -) of the flat band voltage? Briefly explain your reasoning.
c) What is the polarity (+ or -) of the threshold voltage? Briefly explain your reasoning.
d) Is this an enhancement mode or depletion mode device? Briefly explain your reasoning.
e) Sketch the charge density <u>in the semiconductor</u> for this structure at zero gate bias (V_G = 0) and idenitify the source of each block of charge.

10.1 The dc charge distributions of four ideal MOS capacitors are shown in Figure P10.1. For each case: (*a*) Is the semiconductor n or p type? (*b*) Is the device biased in the accumulation, depletion, or inversion mode? (*c*) Draw the energy-band diagram in the semiconductor region.

*Note: the grey areas are fixed charge and the blue areas are mobile charge. See figure below.

10.12 A 400-Å oxide is grown on p-type silicon with $N_a = 5 \times 10^{15}$ cm^{-3}. The flat-band voltage is -0.9 V. Calculate the surface potential at the threshold inversion point as well as the threshold voltage assuming negligible oxide charge. Also find the maximum space charge width for this device.

10.16 An n$^+$ polysilicon gate–silicon dioxide–silicon MOS capacitor has an oxide thickness of $t_{ox} = 18$ nm $= 180$ Å and a doping of $N_a = 10^{15}$ cm^{-3}. The oxide charge density is $Q'_{ss} = 6 \times 10^{10}$ cm^{-2}. Calculate the (*a*) flat-band voltage and (*b*) threshold voltage.

10.35 The parameters of an n-channel MOSFET are $k'_n = 0.6$ mA/V^2 and $V_T = 0.8$ V. The drain current is 1 mA with applied voltages of $V_{GS} = 1.4$ V, $V_{SB} = 0$, and $V_{DS} = 4$ V. (*a*) What is the W/L value? (*b*) What is the value of I_D for $V_{GS} = 1.85$ V, $V_{SB} = 0$, and $V_{DS} = 6$ V? (*c*) Determine the value of I_D for $V_{GS} = 1.2$ V, $V_{SB} = 0$, and $V_{DS} = 0.15$ V.

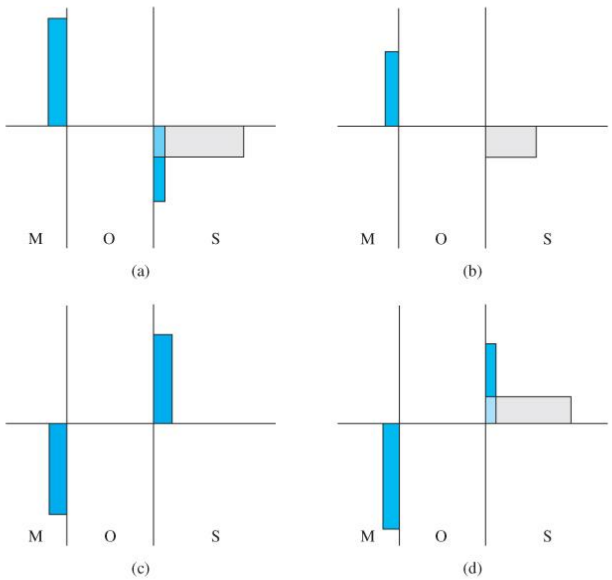
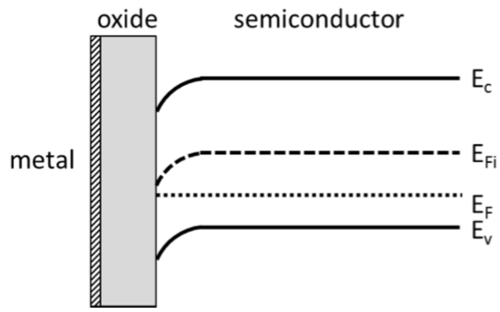


Figure P10.1 | Figure for Problem 10.1.

1) Consider a non-ideal MOS structure with the following band diagram at zero gate bias ($V_G = 0$).



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b) What is the polarity (+ or -) of the flat band voltage? Briefly explain your reasoning.
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e) Sketch the charge density in the semiconductor for this structure at zero gate bias ($V_G = 0$) and idenitify the source of each block of charge.

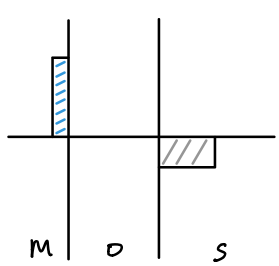
(a) $E_{Fi} > E_F$ ∴ p-type and nMOS technology

(b) positive because the bands are bending down

(c) negative because need to apply a negative bias to turn it off

(d) depletion because $V_T < 0$ (on @ $V_g = 0$)

(e)



blue = mobile charge
grey = fixed charge

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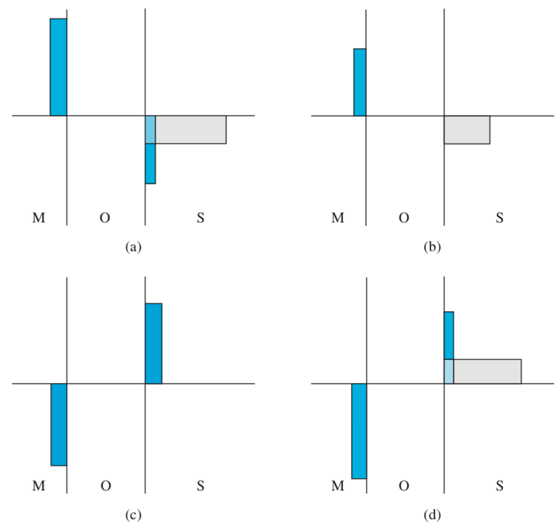
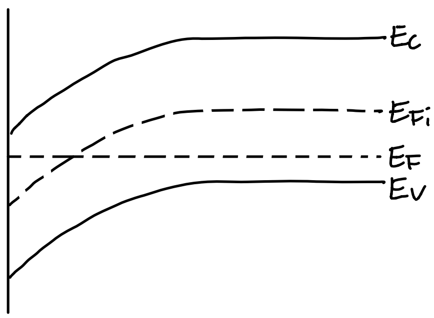


Figure P10.1 | Figure for Problem 10.1.

(A) (a) p-type

(b) inversion

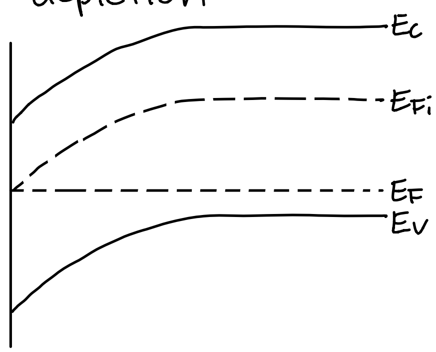
(c)



(B) (a) p-type

(b) depletion

(c)



nMOS (n-channel on p-substrate)

– $V_T < 0 \rightarrow$ **depletion mode (on at $V_G = 0$)**. Need to apply a negative bias to turn the channel "off".

– $V_T > 0 \rightarrow$ **enhancment mode (off at $V_G = 0$)**. Need to apply a positive bias to turn the channel "on".

pMOS (p-channel on n-substrate)

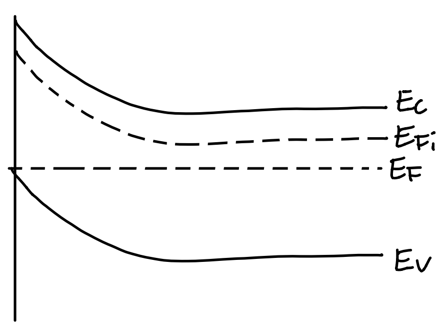
– $V_T < 0 \rightarrow$ **enhancement mode (off at $V_G = 0$)**. Need to apply a negative bias to turn the channel "on".

– $V_T > 0 \rightarrow$ **depletion mode (on at $V_G = 0$)**. Need to apply a positive bias to turn the channel "off".

(C) (a) p-type

(b) accumulation

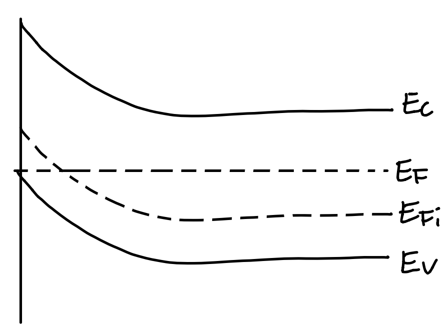
(c)



(D) (a) n-type

(b) inversion

(c)



10.12 A 400-Å oxide is grown on p-type silicon with $N_a = 5 \times 10^{15}$ cm^{-3}. The flat-band voltage is -0.9 V. Calculate the surface potential at the threshold inversion point as well as the threshold voltage assuming negligible oxide charge. Also find the maximum space charge width for this device.

$$\phi_{Fp} = \frac{kT}{e} \ln\left(\frac{N_a}{n_i}\right) = 0.0259 \ln\left(\frac{5 \times 10^{15}}{1.5 \times 10^{10}}\right) = 0.32937$$

$$|Q'_{SD}(max)| = eN_a x_{dT}$$

$$x_{dT} = \left(\frac{4\epsilon_s \phi_{Fp}}{eN_a}\right)^{1/2}$$

$$\boxed{= 4.1276 \times 10^{-5} \text{ cm}}$$

$$= 3.30657 \times 10^{-8} \frac{C}{cm^2}$$

$$V_{TN} = \left(|Q'_{SD}(max)| - \cancel{Q'_{SS}}^{\,0}\right)\left(\frac{t_{ox}}{\epsilon_{ox}}\right) + \phi_{ms} + 2\phi_{Fp}$$

$$= (3.30657 \times 10^{-8})\left(\frac{400 \times 10^{-8}}{3.9 \times 8.85 \times 10^{-14}}\right) + (-0.9) + 2(0.32937)$$

$$\boxed{= 0.141758 \text{ V}}$$

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(a) $$V_{FB} = \phi_{ms} - \frac{Q'_{SS}}{C_{ox}} = 1.1 - \frac{(6\times10^{10})(180\times10^{-8})(1.6\times10^{-19}C)}{(3.9)(8.85\times10^{-14})}$$

$$\boxed{= -1.1468\,V}$$

(b)

$$\phi_{Fp} = \frac{KT}{e}\ln\left(\frac{N_a}{n_i}\right) = 0.0259\ln\left(\frac{1\times10^{15}}{1.5\times10^{10}}\right) = 0.28768$$

$$|Q'_{SD}(max)| = eN_a x_{dT} \qquad x_{dT} = \left(\frac{4\epsilon_s\phi_{Fp}}{eN_a}\right)^{1/2}$$

$$= 1.38201\times10^{-8}\ \frac{c}{cm^2} \qquad = 8.6258\times10^{-5}\ cm$$

$$V_{TN} = \left(|Q'_{SD}(max)| - Q'_{SS}\right)\left(\frac{t_{ox}}{\epsilon_{ox}}\right) + \phi_{ms} + 2\phi_{Fp}$$

$$\boxed{= -0.502704\ V}$$

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(a) $V_{DS} > V_{gs} - V_T$ (saturation)

$$I_D = \frac{k_n'}{2}\left(\frac{W}{L}\right)_n (V_{gs} - V_T)^2$$

$$\left(\frac{W}{L}\right)_n = \frac{2 I_D}{k_n' (V_{gs} - V_T)^2} = \boxed{9.25926}$$

(b) $V_{DS} > V_{gs} - V_T$ (saturation)

$$I_D = \frac{k_n'}{2}\left(\frac{W}{L}\right)_n (V_{gs} - V_T)^2 = \boxed{3.0625\text{ mA}}$$

(c) $V_{DS} < V_{gs} - V_T$ (linear)

$$I_D = k_n'\left(\frac{W}{L}\right)(V_{gs} - V_T)\,V_{DS} - \frac{V_{DS}^2}{2} = \boxed{270.83\,\mu A}$$